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CHARACTERISTICS OF SELECTED REFERENCE TARGETS
FOR CALIBRATING 10.6- μ m LASER RADARS

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by

H. Henshall and J.M. Cruickshank

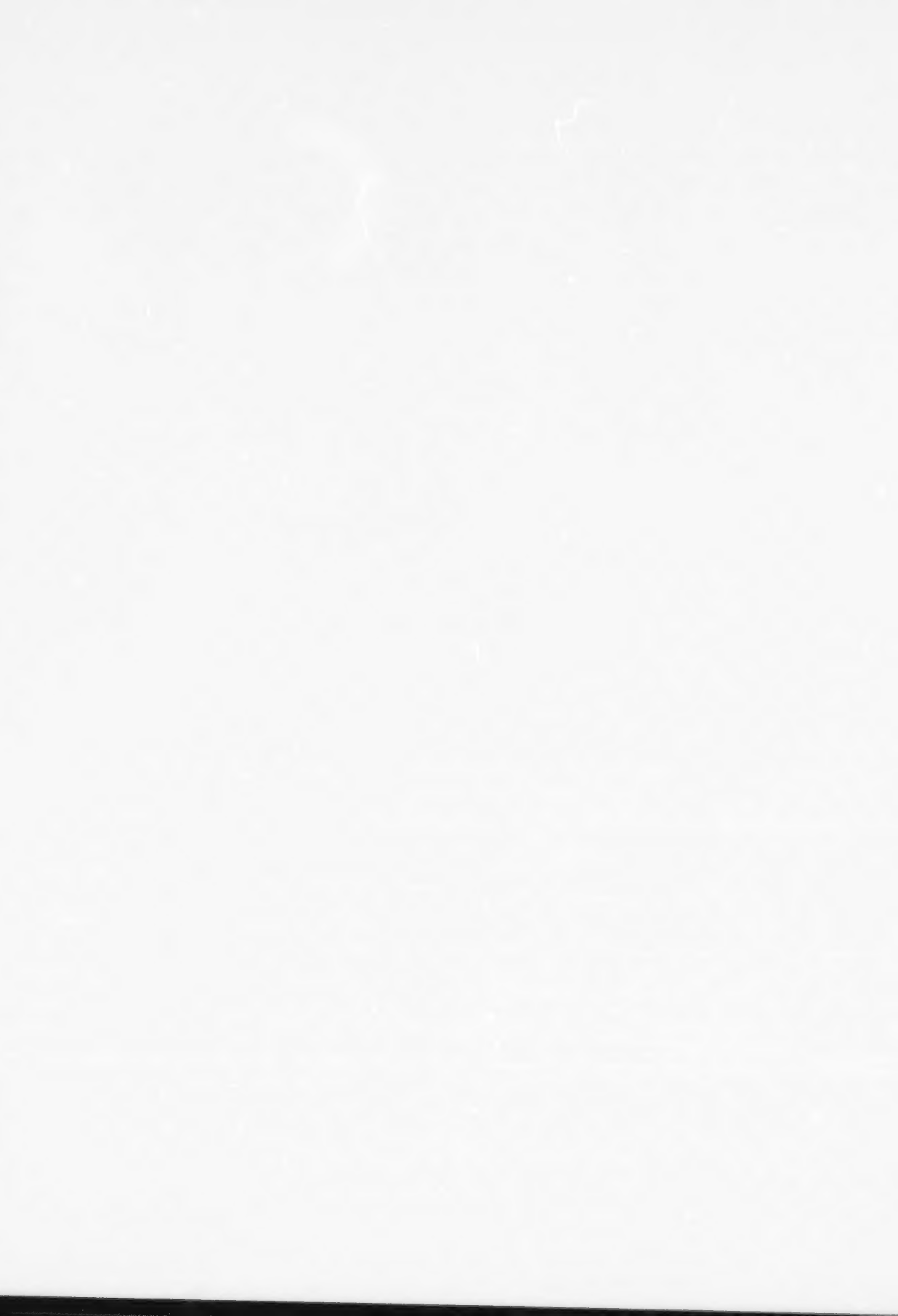
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ABSTRACT

The reflective characteristics of several materials have been examined in an effort to develop a 10.6- μm reflectivity standard for field measurements with laser radars. Measurements on twelve different target materials showed that many materials have components of diffuse reflectivity, specular reflectivity, and retroreflectivity. For each material examined, both the effective Lambertian reflectivity and the beam depolarization were determined. It was also found that because of the strong retroreflection component present in many materials, the practice of estimating the effective diffuse reflectivity from measurements of total reflectivity could lead to erroneous reflectivity values for laser radar systems. One of the preferred reference targets found for 10.6- μm field measurements was canvas tarpaulin.

RÉSUMÉ

En vue d'établir un étalon de réflectivité à 10.6 μm pour des mesures absolues avec des radars à laser, les caractéristiques de réflectivité de plusieurs matériaux ont été examinées. Les mesures effectuées sur douze cibles de matériaux divers ont montré des composantes de réflectivité diffuse, de réflectivité spéculaire et de rétro-réflectivité. Pour chaque matériau étudié, la réflectivité lambertienne efficace et la dépolarisation du faisceau ont été déterminées. On a aussi trouvé que par suite de la présence dans plusieurs matériaux d'une forte composante de rétro-réflexion, la pratique d'estimer la réflectivité diffuse efficace à partir des mesures de réflectivité totale pourrait résulter en des valeurs erronées de réflectivité pour les systèmes de radar à laser. Une bâche en toile s'est révélée la cible de référence préférée pour des mesures absolues à l'extérieur à 10.6 μm .



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1.0 INTRODUCTION

Laser radar systems based on either direct or heterodyne detection are normally calibrated for signal amplitude measurements by using a reference panel with known reflectance characteristics. In our quest for a reliable, calibrated reference standard we examined a number of materials commonly used for this purpose. We had hoped to find an easy to handle, well-characterized material for a field standard at 10.6 μm . It was discovered that some targets have components of diffuse reflectivity, specular reflectivity and retroreflectivity. Although the phenomenon of retroreflectivity has been observed from diffuse surfaces in the visible wavelengths (Refs. 1,2), to our knowledge little has been published on retroreflectivity from 10.6- μm reference targets.

For a laser radar system in a field situation, the power per steradian reflected back towards the receiver from an extended Lambertian target is given by:

$$\frac{\rho_o \cos \beta}{\pi} \times P_i \quad [1]$$

where ρ_o is the total reflectance of the target

β is the angle between the receiver axis and the normal to the target surface, and

P_i is the power incident on the target.

Since true Lambertian reflectors are rare and not all targets are plane surfaces, it is convenient to use another term ρ , sometimes called diffuse reflectivity or effective Lambertian diffuse reflectivity, to replace $\rho_o \cos \beta$ in eq. 1. The parameter ρ is simply the received signal power relative to the power which would be received from an ideal (100%) Lambertian reflector with $\beta = 0^\circ$. It is understood that ρ is a function of the target aspect angle, however it is defined, and also of the transmitted and received beam polarizations.

This report will demonstrate that determining a target's diffuse reflectivity ρ from measurements of total reflectance ρ_0 often proves to be inaccurate for laser radar applications.

In a previous report (Ref. 3), the reflectivity characteristics as a function of the target aspect angle were presented for many materials. In the open literature, reports are found on other materials which have been used for 10.6- μ m reference targets. We have now found that the reflectivity of many of these materials is less Lambertian than indicated in the publications.

The following reference target materials are discussed in this report:

- a) polystyrene foam (blue): Styrofoam SM, Dow Chemicals of Canada;
- b) exposed polystyrene foam (blue): as above - exposed one year outdoors;
- c) polystyrene foam (blue): sample obtained from USA;
- d) silicon carbide abrasive: Norton Closekote Durite SiC 80C waterproof paper;
- e) silicon carbide abrasive: Norton Closekote Durite SiC 150C waterproof paper;
- f) silicon carbide abrasive: Norton Closekote Durite SiC 400A waterproof paper;
- g) gold coated sandblasted aluminum: coarse;
- h) gold coated sandblasted aluminum: fine;
- i) sandblasted aluminum: coarse;
- j) canvas: marine and tent duck, color mineral linen (Otis Permasol 10 oz. treated);
- k) jute cloth, burlap: Scythes Inc. Toronto 10 oz. natural jute;
- l) sublimed sulfur: Fisher Scientific Co. Sublimed Sulfur S591.

The surfaces of all three polystyrene targets were prepared by sanding with 120-grit sandpaper to remove the outer glazed surface and to expose porous-looking inner material composed of hollow spherical cavities cut open randomly to varying depths. The sublimed sulfur target was prepared by the method described in Ref. 4 to form a flat surface supported in a metal holder.

This work was performed at DREV between September 1983 and February 1986 under PCN 33H05, Preliminary Study for Laser Radars.

2.0 EFFECT OF TARGET ASPECT ANGLE

The commonly performed measurement on the reflectivity of materials consists in directing the laser source at an extended target and measuring the reflected signal power as the target is turned to change the aspect angle. In the standard configuration, the laser beam and the receiver field of view (FOV) are on the same optical axis and the detector FOV is wide enough to collect energy from the full extent of the spot illuminated by the laser. Even if the absolute value of reflectivity is not known, relative reflectivity can be plotted as a function of the target aspect angle. For preferred reference targets, the reflectivity varies in a smooth and predictable manner with the aspect angle. A good example is the Lambertian reflector for which the detected signal power varies as the cosine of the angle between the normal to the target surface and the axis of the receiver.

2.1 Measurement Apparatus

Figure 1 illustrates the apparatus used for this investigation. It comprises a continuous (CW) CO₂ laser which is linearly polarized, amplitude-stabilized with a lock-in stabilizer, and grating tuned to 10.6 μm . The output beam is chopped by a chopper blade having one mirrored surface which, when the beam is cut, directs the laser beam onto a power meter to continuously monitor the output power. The

chopper unit also provides a synchronizing pulse for the lock-in amplifier. The laser beam is attenuated with calcium fluoride (CaF_2) windows before impinging on the target surface. Because the optical attenuation provided by the CaF_2 windows varies with temperature (i.e. approximately $1\%/^\circ\text{C}$ for a 10 x attenuator) and the laboratory temperature varied by up to 12°C during a day, the attenuating windows were mounted in a thermally controlled ($30^\circ\text{C} \pm 0.25^\circ\text{C}$) box with apertures for the laser beam. Also, tests were only begun after the attenuator heating due to the laser beam had stabilized. Each target material to be investigated was prepared in the form of a disc (10- to 15-cm diam.) and was spun on its axis during each measurement such that the speckle-induced power fluctuations (Ref. 5) seen by the detector could be averaged. The target holder was mounted in such a manner that it could be turned in azimuth while maintaining the center of the laser beam at a fixed spot on the target's front surface above the pivot point. This arrangement kept the target-to-detector distance constant and ensured that the same portion of the target was illuminated at each target illumination angle. The detector, without any collecting optics, was mounted on a pivoting arm at 0.84 m from the target. The detector's 30° field of view was large compared to that needed for the laser spot size of 1.7 cm on the target. The detected signal and the synchronizing pulse from the chopper assembly are fed to a lock-in amplifier which produces a speckle-averaged value of signal power.

For our work the angles β , θ and α were defined as shown in Fig. 1. β , the detector viewing angle, is the angle between the normal to the surface of the target and the detection axis. θ , the target illumination angle, is the angle between the normal to the surface of the target and the axis of the laser beam. α is the angle from the detection axis to the laser beam axis (i.e. $\alpha = \theta - \beta$). In a true monostatic configuration $\beta = \theta$ (i.e. $\alpha = 0$) and this single angle is commonly referred to as the target aspect angle. For our investigation on the effect of aspect angle, measurements were made on a configuration which was close to monostatic (i.e. $\alpha = 3^\circ$) because α could not be

reduced to zero without obscuring part of the laser beam. There is no reason to believe that the general shape of the curves plotted from the measured data would vary significantly from that obtained with a truly monostatic system. These curves are only used to establish if the target reflectivity varies in a smooth and predictable manner with the aspect angle.

2.2 Results

In Fig. 2, the measured reflectivity of several target materials has been plotted as a function of the detector viewing angle β with the target illumination angle $\theta = \beta + 3^\circ$. This measurement was carried out by pivoting the target holder on its base (step sizes as small as 0.5 deg) and recording the signal measured with the HgCdTe detector and lock-in amplifier for each detector viewing angle. α remained unchanged at 3° . To convert the measured signal into a value of target reflectivity, a conversion constant derived by the procedure described in Chapter 4.0 was applied to each value. Each plotted curve is based on the average of several sets of curve data. The dashed curve is the least squares cosine best fit to the measured reflectivity curve. A cosine response would be produced by a true Lambertian reflector in this measurement configuration (i.e. the detector FOV is larger than the radiating source). On the other hand, measuring a cosine response does not guarantee that the target has a Lambertian reflectivity. This last point will be made more evident with the measurements in Chapter 3.0.

3.0 ANGULAR DISTRIBUTION OF REFLECTED POWER

This set of measurements, which shows the angular distribution of the backscattered radiation, is particularly important for laser radar systems because of the small solid angle over which reflected radiation is collected. With reference to Fig. 1, the measurement was carried out by setting the target illumination angle θ at a fixed value

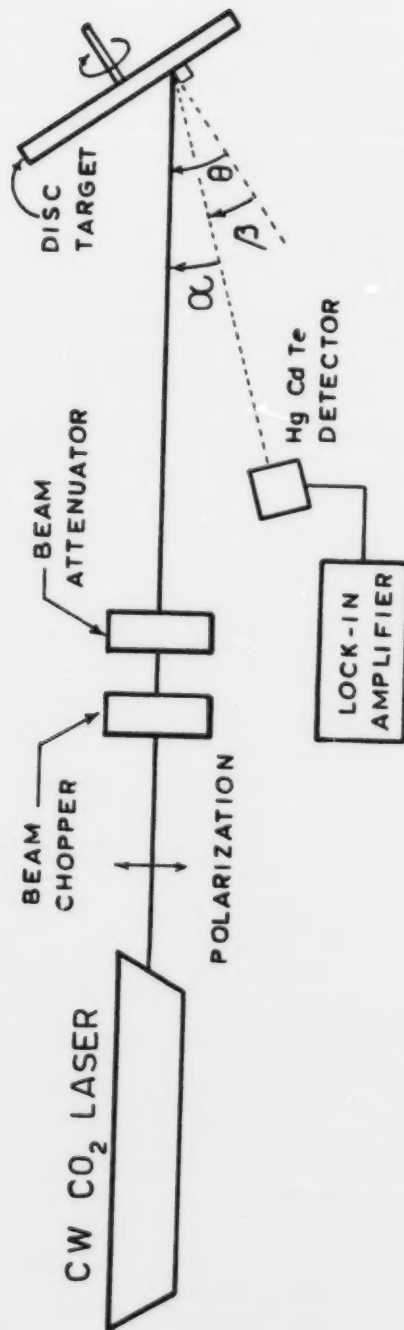


FIGURE 1 - Basic apparatus for measuring reflectivity characteristics of targets. Notes: (1) Target surface and detector arm pivot independently about spot illuminated on surface of target. (11) $|\alpha|$ must be $> 3^\circ$ for detector not to block laser beam.

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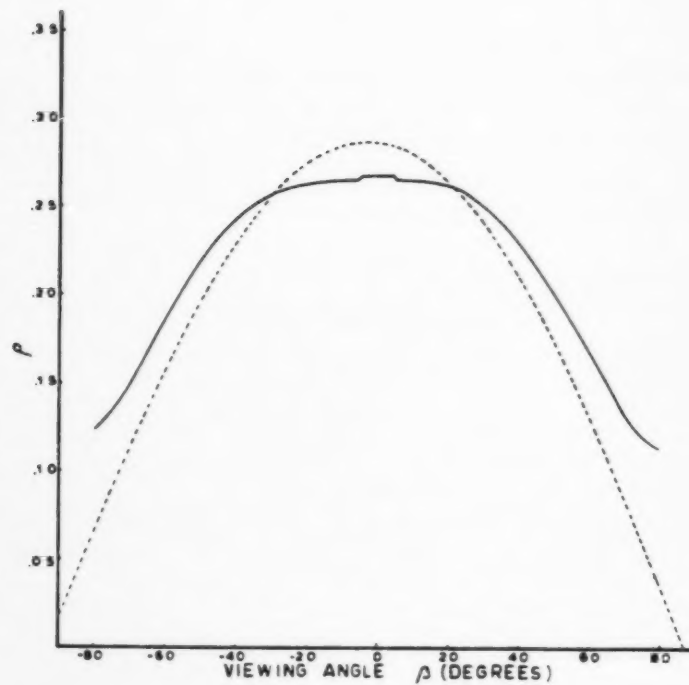


FIGURE 2a - Blue polystyrene foam (Styrofoam SM, Dow Chemicals of Canada)

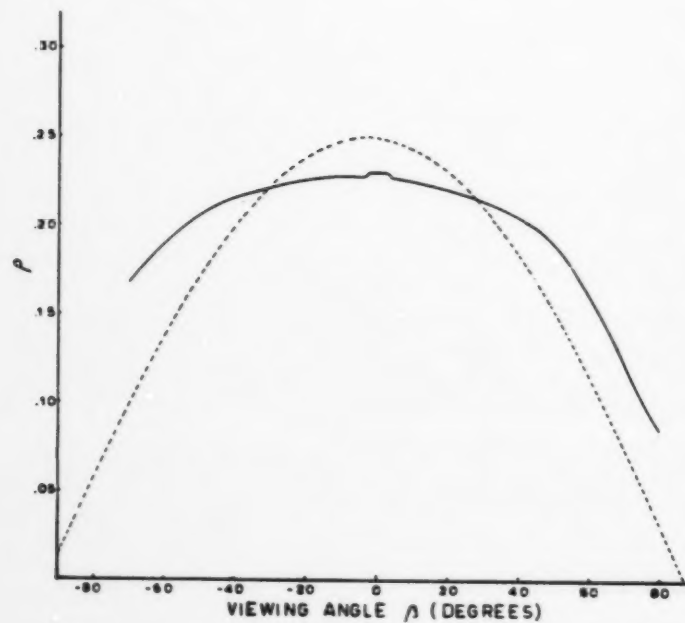


FIGURE 2b - Exposed blue polystyrene foam (same as Fig. 2a except surface deteriorated by weathering)

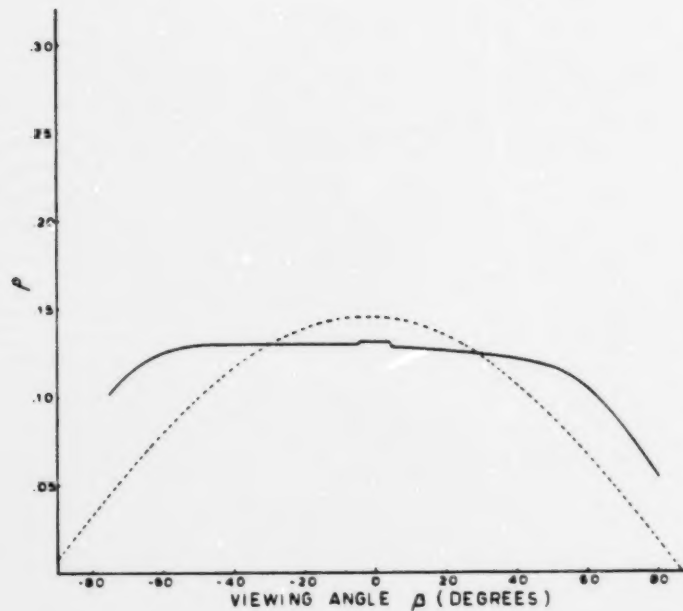


FIGURE 2c - USA blue polystyrene foam (sample obtained from Canada - US exchange)

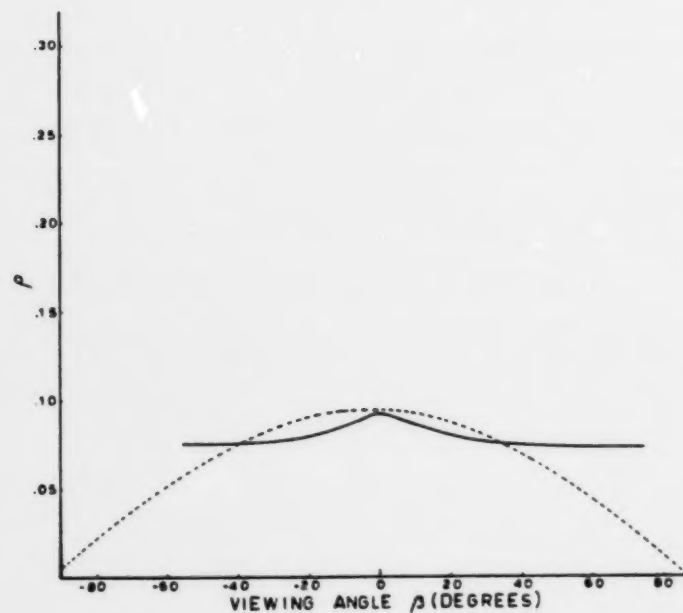


FIGURE 2d - Silicon carbide abrasive (Norton Closekote Durite SiC 80C waterproof paper)

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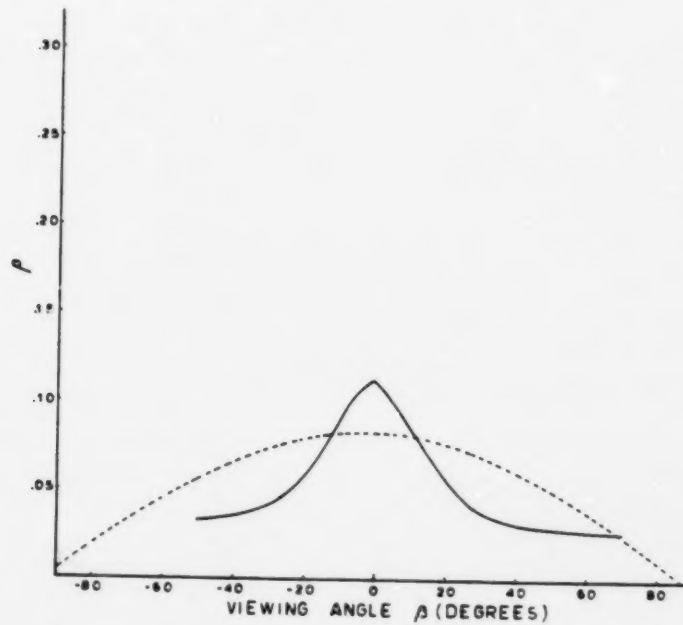


FIGURE 2e - Silicon carbide abrasive (Norton Closekote Durite SiC 150C waterproof paper)

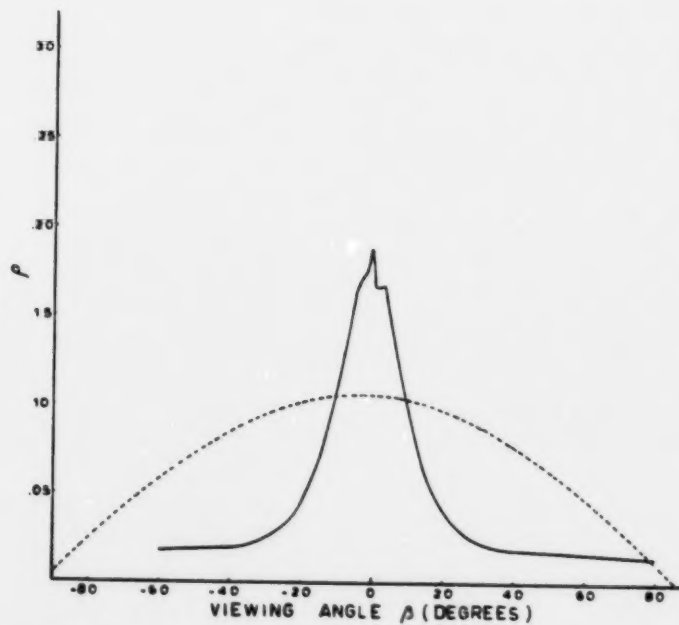


FIGURE 2f - Silicon carbide abrasive (Norton Closekote Durite SiC 400A waterproof paper)

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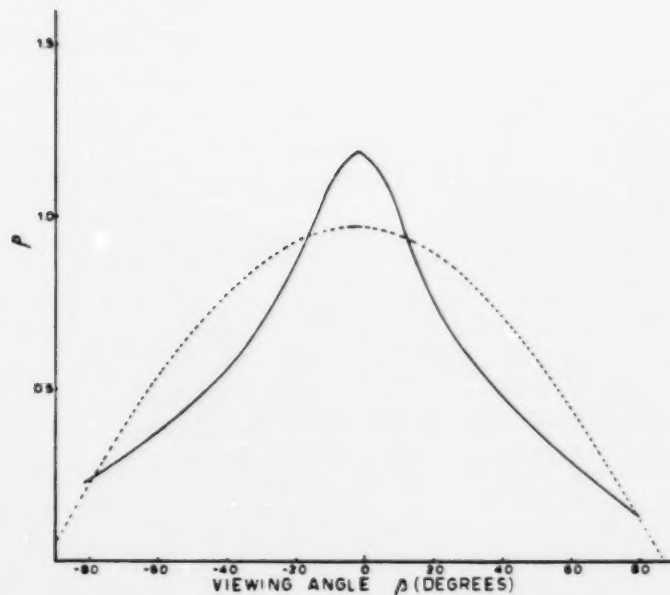


FIGURE 2g - Gold coated, coarsely sandblasted aluminum

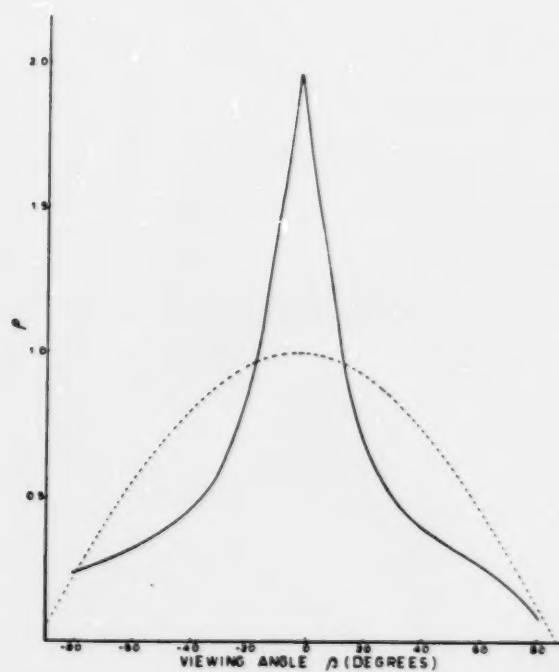


FIGURE 2h - Gold coated, finely sandblasted aluminum

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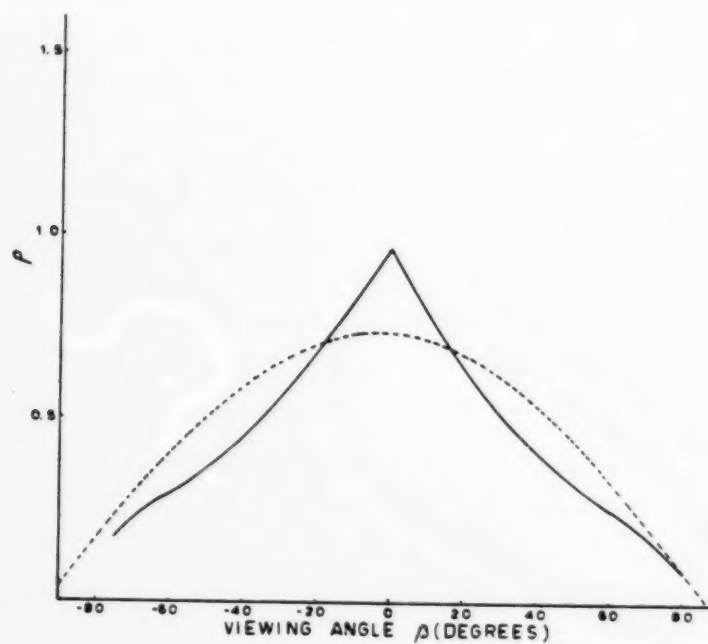


FIGURE 21 - Coarsely sandblasted aluminum

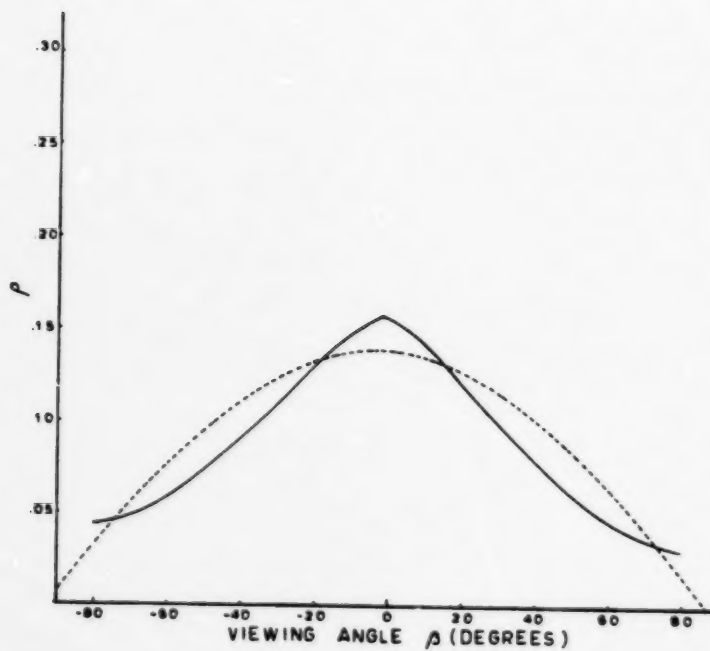


FIGURE 2j - Canvas marine and tent duck, color mineral linen (Otis Permasol 10 oz. treated)

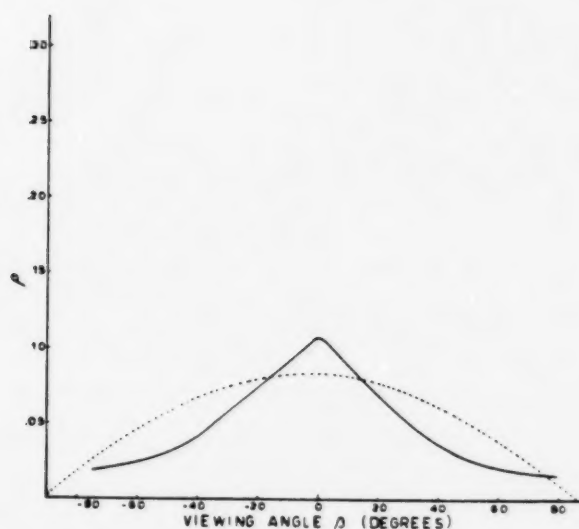


FIGURE 2k - Jute cloth (10 oz. natural jute, Scythes Inc. Toronto)

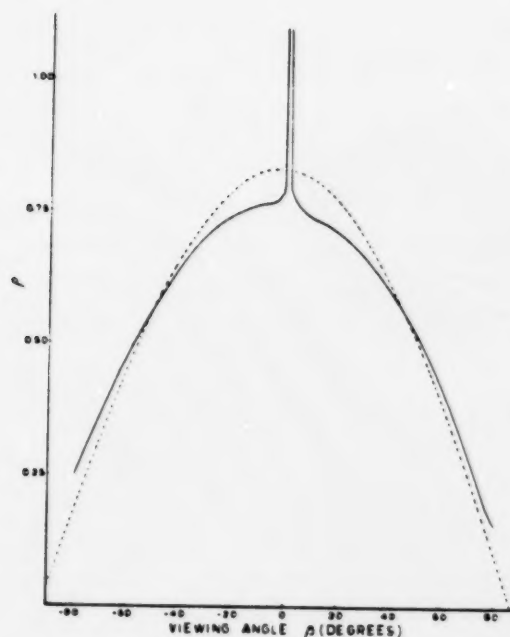


FIGURE 2l - Sublimed sulfur (Sublimed Sulfur S591, Fisher Scientific Co.). The off-scale peak value for ρ is 1.36.

FIGURE 2 - Reflectivity ρ versus detector viewing angle β with the target illumination angle $\theta = \beta + 3^\circ$. The dashed curve is the least squares cosine best fit to the measured reflectivity curve.

and measuring the signal detected at different detector viewing angles β . Simply stated, the target remained at a fixed angular position and the detector was scanned through its angular positions. The detected signals were then converted into values of target reflectivity (see Chapter 4.0) before being plotted.

3.1 Measurement Apparatus

The apparatus shown in Fig. 1 proved useful for this series of measurements except in the angular ranges where the detector would have blocked the laser beam (i.e. $\alpha < |3^\circ|$). As most laser radar systems operate in a configuration with α close to zero, a measurement of target reflectivity was considered essential for values of $\alpha < |3^\circ|$ and the original apparatus was modified for these measurements. The modified measurement apparatus, shown in Fig. 3, has a 45 cm $\times$ 50 cm pellicle beam splitter mounted vertically with its horizontal axis at 45° to the laser beam. The beam splitter deflects a desired small part of the beam onto the target while allowing the unwanted major portion of the beam to be completely dissipated by an absorbing screen. The targets were again mounted on a spinning motor for speckle averaging. The backscattered radiation passed through the beam splitter to the detector with some loss. Again the pivot point for turning the target coincided with the point around which the detector was angularly scanned. Because of the variation with angle in the transmission characteristics of the pellicle beam splitter, this modified measurement configuration was only used over the angular conditions with $\alpha < |\pm 10^\circ|$.

To verify that measurements made with the pellicle beam splitter were accurate, an additional modification was made to the original apparatus as shown in Fig. 1. The detector was placed at a greater distance (i.e. 2.2 m) from the target in order to allow a direct measurement of the backscattered radiation for angles of α as low as 0.8° before blocking the laser beam with the detector. A collecting

lens was used in front of the detector to increase the level of the detected signal. The plots of target reflectivity described in Section 3.2 are based on data taken with all three measurement arrangements.

3.2 Results

The reflectivity characteristics of twelve targets were examined with the different apparatus configurations described in Section 3.1. Plots of reflectivity versus detector viewing angle β for target illumination angles of $\theta = 0^\circ$ and $\theta = 30^\circ$ are shown in Fig. 4. The plots include data accumulated with the three apparatus configurations described (i.e. the apparatus of Fig. 1, apparatus of Fig. 3, and apparatus of Fig. 1 with the detector at a greater distance). Good agreement was found in the data for the angular positions where more than one measurement apparatus was used.

The dashed lines on the plotted curves represent the reflectivity which would be measured for $\theta = 0$ and a Lambertian surface whose total reflectance is equivalent to that of the target. In other words, the dashed line is defined by $\rho_0 \cos \beta$ where ρ_0 is the total reflectance of the target. Total reflectance could have been measured with the standard technique of using an integrating sphere for the appropriate wavelength, but this apparatus was not readily available. An alternative method of calculating the total reflectance would be to scan a single detector over a hemispherical surface centered on the target's illuminated spot and sum the individual powers measured for each surface element of hemisphere. However, because the target is being spun on its axis, the distribution of reflected energy was assumed symmetrical about the illuminated spot on the target. The reflected power density was measured with our apparatus in a scan from $\beta = +90^\circ$ through $\beta = 0^\circ$ to $\beta = -90^\circ$ (i.e. bisecting the hemisphere of reflected power). The total reflected power was determined by assigning these measured power densities to all identical values of β on the surface of a hemisphere and calculating the total power inter-

cepting the hemisphere. The total reflectance was then calculated from the ratio of the total reflected power to the total incident power.

To give an alternative representation of the reflectivity as a function of β , the information used for the curve of $\theta = 0^\circ$ in Fig. 4 has been replotted with polar coordinates in Appendix A (Fig. A1). The reflectivity which would have been measured from an equivalent Lambertian surface is displayed as a circle in polar coordinates.

4.0 CALIBRATED VALUES OF REFLECTIVITY

The values of ρ plotted in Figs. 2 and 4 were determined from measurements made with a HgCdTe photovoltaic (PV) detector at 77 K. This sensitive detector coupled to a lock-in amplifier gave adequately stable readings of output voltage for the lower values of reflected power encountered. To convert the output voltages measured with the PV detector into the values of reflectivity given in Chapters 2.0 and 3.0, the procedure described below was used.

By substituting ρ for $\rho_0 \cos \beta$ in eq. 1, the power per steradian reflected back from a target is $\frac{\rho}{\pi} \cdot P_i$ where P_i is the power incident on the target and ρ is the reflectivity for a particular detector viewing angle β . Therefore the power received by the detector is:

$$P_r = \left(\frac{A_r}{R^2} \right) \cdot \frac{\rho}{\pi} \cdot P_i \quad [2]$$

where A_r is the area of the receiver and R is the distance between the target and the receiver. In the above, A_r and R^2 are used to define the solid angle over which power is detected. Equation 2 can be rewritten as:

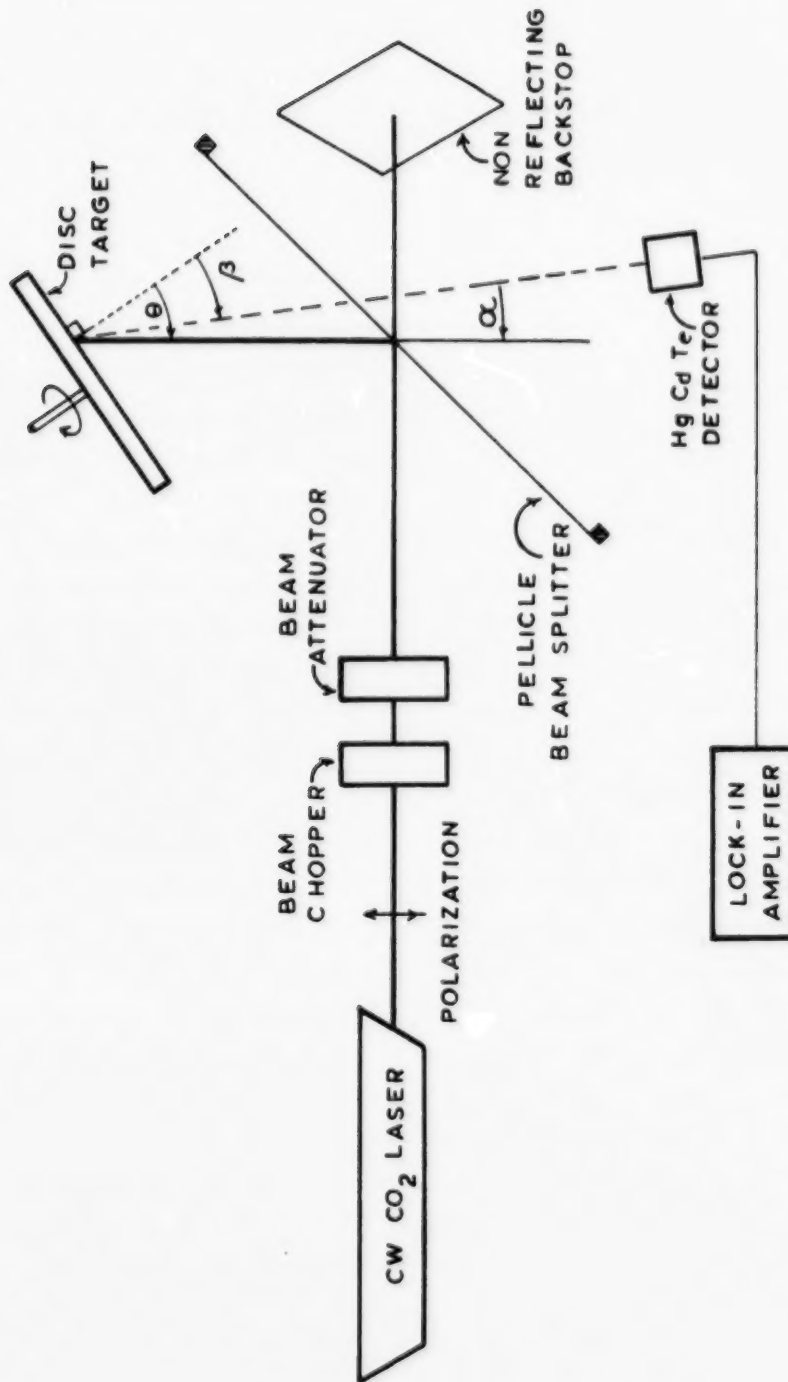


FIGURE 3 - Apparatus used to measure target reflectivity for $\alpha < |\pm 3^\circ|$

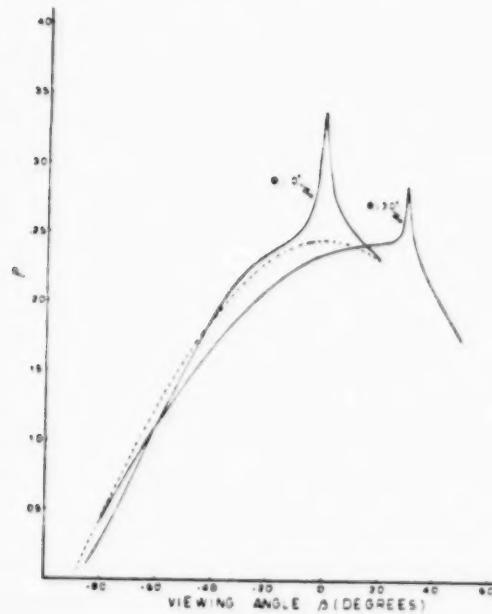


FIGURE 4a - Blue polystyrene foam (Styrofoam SM, Dow Chemicals of Canada)

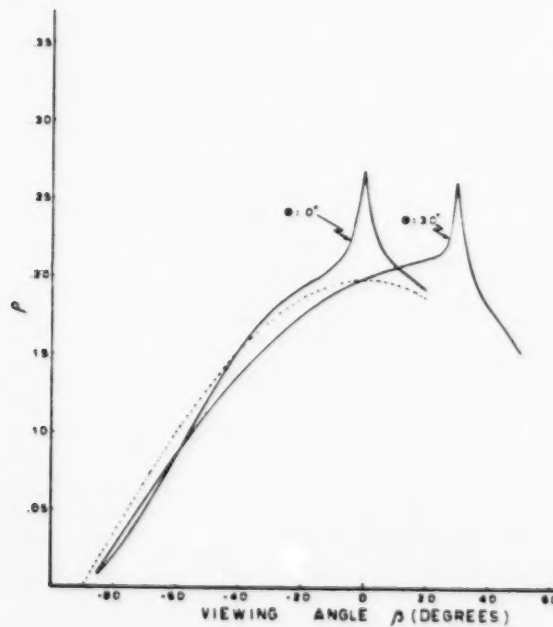


FIGURE 4b - Exposed blue polystyrene foam (same as Fig. 4a except surface deteriorated by weathering)

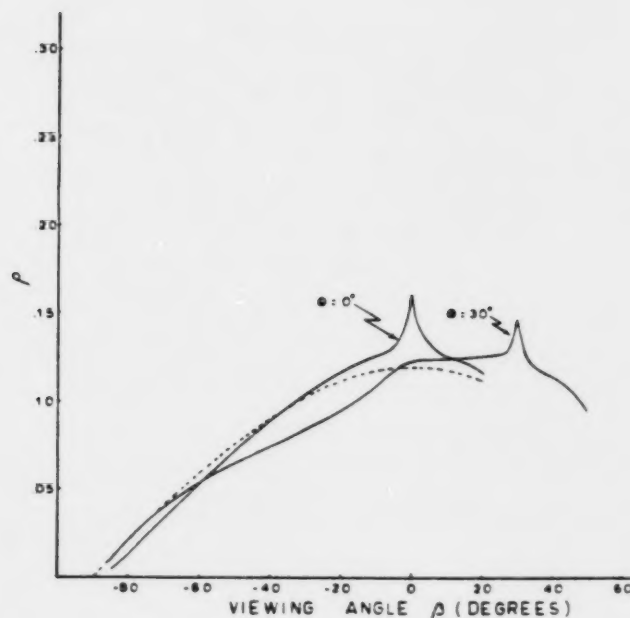


FIGURE 4c - USA blue polystyrene foam (sample obtained from Canada - US exchange)

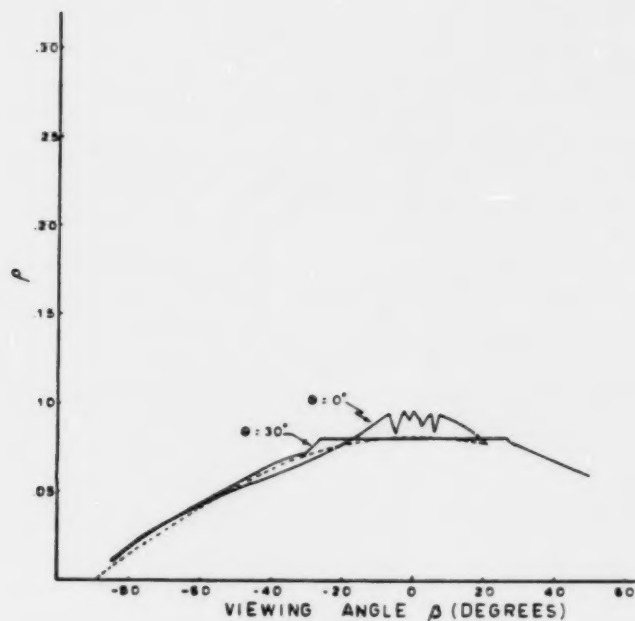


FIGURE 4d - Silicon carbide abrasive (Norton Closekote Durite SiC 80C waterproof paper)

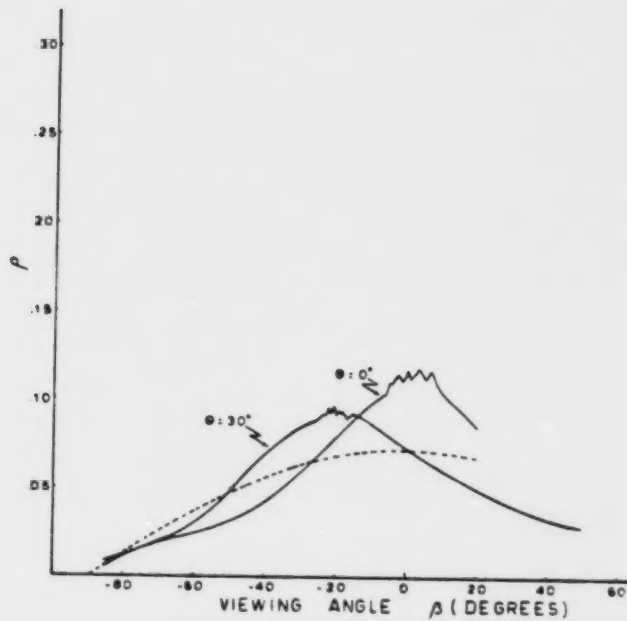


FIGURE 4e - Silicon carbide abrasive (Norton Closekote Durite SiC 150C waterproof paper)

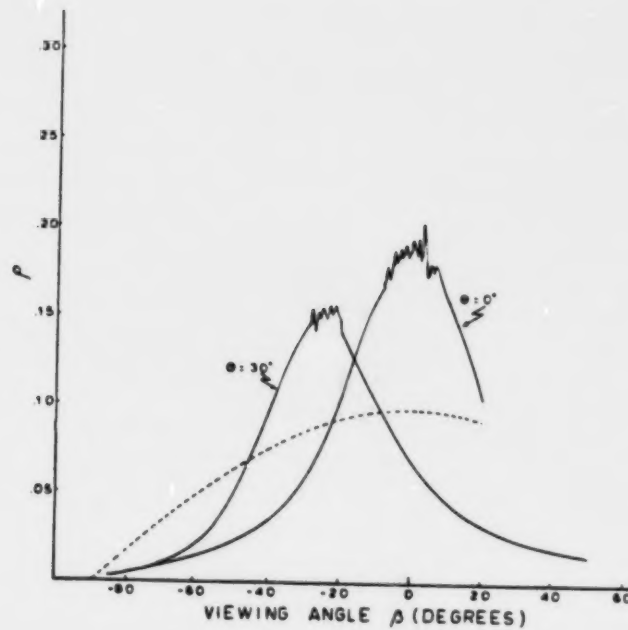


FIGURE 4f - Silicon carbide abrasive (Norton Closekote Durite SiC 400A waterproof paper)

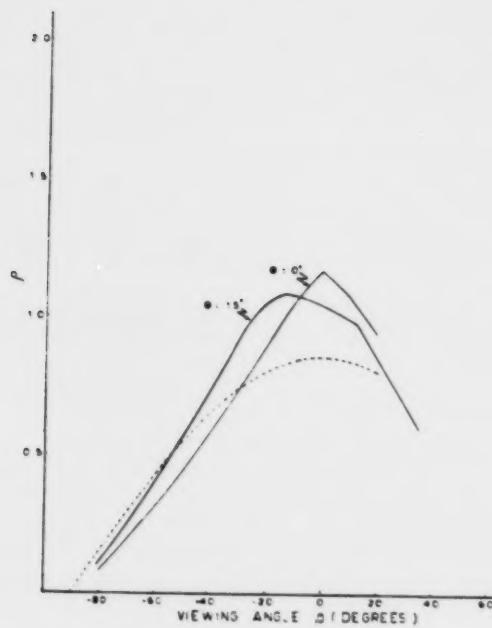


FIGURE 4g - Gold coated, coarsely sandblasted aluminum

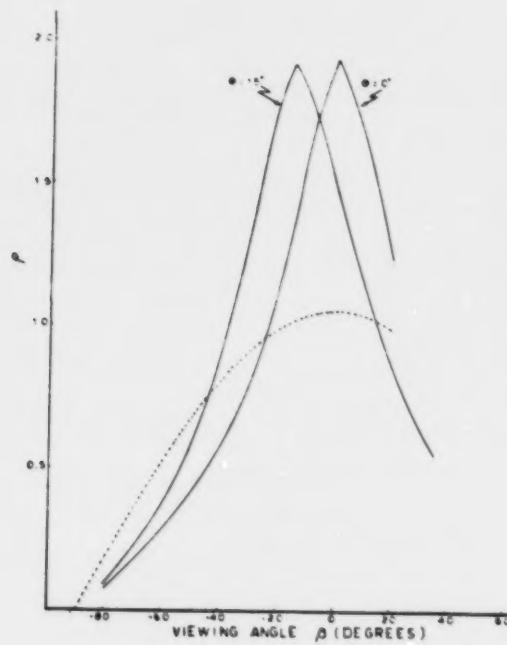


FIGURE 4h - Gold coated, finely sandblasted aluminum

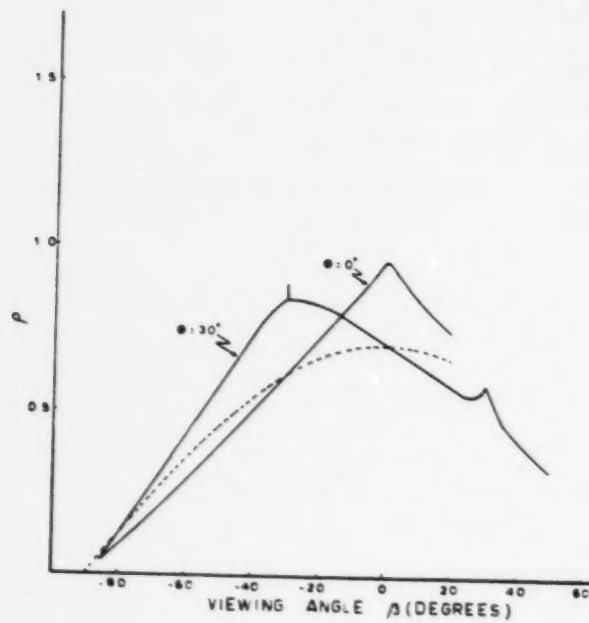


FIGURE 4i - Coarsely sandblasted aluminum

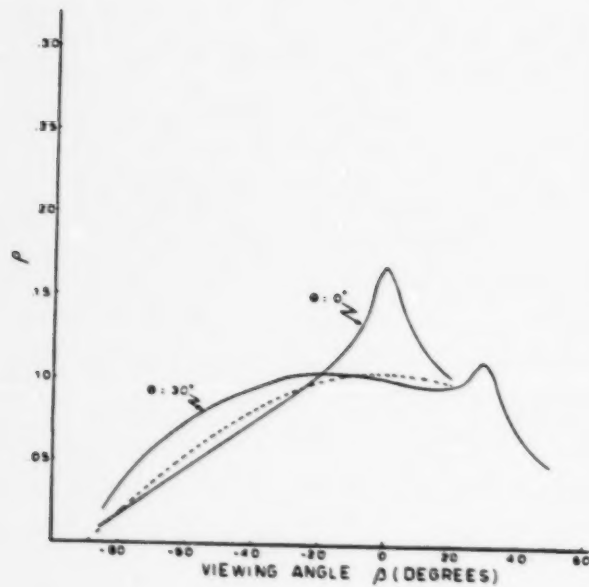


FIGURE 4j - Canvas marine and tent duck, color mineral linen (Otis Permasol 10 oz. treated)

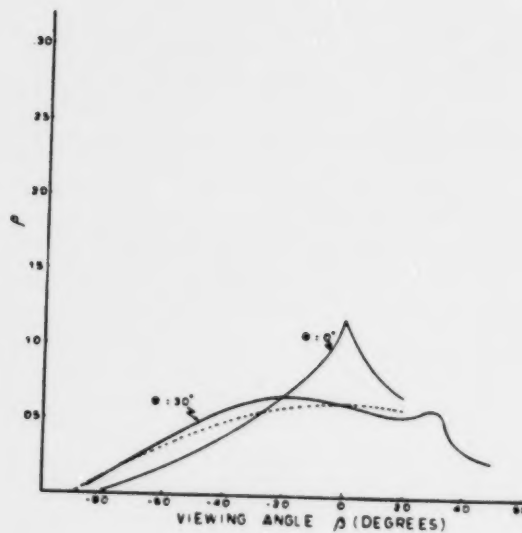


FIGURE 4k - Jute cloth (10 oz. natural jute, Scythes Inc., Toronto)



FIGURE 4l - Sublimed sulfur (Sublimed sulfur S591, Fisher Scientific Co.). The off-scale peak values for ρ at $\theta = 0^\circ$ and 30° are 9.66 and 1.56 respectively.

FIGURE 4 - Reflectivity ρ versus detector viewing angle β for target illumination angles $\theta = 0^\circ$ and $\theta = 30^\circ$. The dashed line is the reflectivity which would be measured from a Lambertian surface with $\theta = 0^\circ$ and a total reflectance equivalent to that of the target.

$$\rho = \left(\frac{R^2}{A_r} \right) \cdot \pi \frac{P_r}{P_i} \quad [3]$$

To determine a value of ρ it is necessary to have accurate measurements of both P_i and P_r . In our measurement setup, the magnitude of these two powers differs enormously (several orders of magnitude). A Scientech Power Energy Meter (Model 362) was chosen to measure P_i and P_r . For this, two power meters were carefully calibrated by supplying power to the internal calibration resistors, mounted on the detector element, with accurately measured voltages and currents. This calibration was carried out in a draft-free, constant-temperature, constant-illumination work area, and was performed both with and without the Isoperibol covers (thermally insulated covers used to isolate the detector head from ambient changes in temperature). After calibration, readings on the two power meters were compared against each other over a large range of laser powers. The difference between the meters for the laser powers agreed with the results of the electrical calibration.

4.1 Measurement of Reflectivity

In Chapters 2.0 and 3.0, the measurements of reflected power for all targets were made relative to the power reflected from a reference target of polystyrene foam (styrofoam) at $\theta = 0^\circ$. It was therefore only necessary to accurately determine the reflectivity of styrofoam at one particular value of β (θ fixed at 0°) in order to have calibrated reflectivity curves for all tested targets at all angles.

The straightforward approach to measuring reflectivity would have been to use the calibrated power meter (Scientech) to measure the incident power on the target and then the reflected power which is detected at range R . However with the styrofoam target, sufficient incident power to obtain a stable reading for the reflected power could not be put on the target without damaging the target's surface charac-

teristics. It was found that the surface of a stationary styrofoam target degraded with incident power densities of $> 2 \text{ mW/mm}^2$.

To overcome this damage problem, the procedure depicted in Fig. 5 was used to calibrate the styrofoam reference target. The Scientech power energy meter was first used to measure the total energy incident on a coarsely sandblasted aluminum target. This aluminum surface could not be damaged even with the full laser power of 2.1 W. The meter was then moved to measure the power passing through an iris of a known diameter and distance R from the target. The detector viewing angle α was 10° for this measurement. With $\alpha = 10^\circ$, the retro-reflected component of the reflected power did not interfere with the calibrating procedure. By using eq. 3, a value of ρ for the sandblasted aluminum at $\alpha = 10^\circ$ ($\theta = 0^\circ$) was determined to be 0.842.

An attenuator was now placed in the laser beam to reduce the incident power density on the aluminum target to a level below which it would not damage a styrofoam target. Also, a HgCdTe detector was substituted for the power and energy meter. Because of the small size of the HgCdTe detector element, the iris was no longer required. The signal level which was now being measured with the HgCdTe detector and lock-in amplifier corresponded to the previously determined target reflectivity of 0.842 (aluminum at $\alpha = 10^\circ$). Knowing that the detected signal was directly proportional to the reflectivity of the target, the styrofoam target was then installed on the rotating motor and its reflectivity determined to be 0.256 ($\alpha = 10^\circ$) from the ratio of the measured signal to the signal from the aluminum target. From this value and the measurements in Chapter 3.0, ρ for styrofoam at $\alpha = 0^\circ$ is 0.345. As previously stated, this styrofoam target with its known reflectivity characteristics was kept as a reference and was used to calibrate the reflectivities of other targets by comparing the relative signal levels.

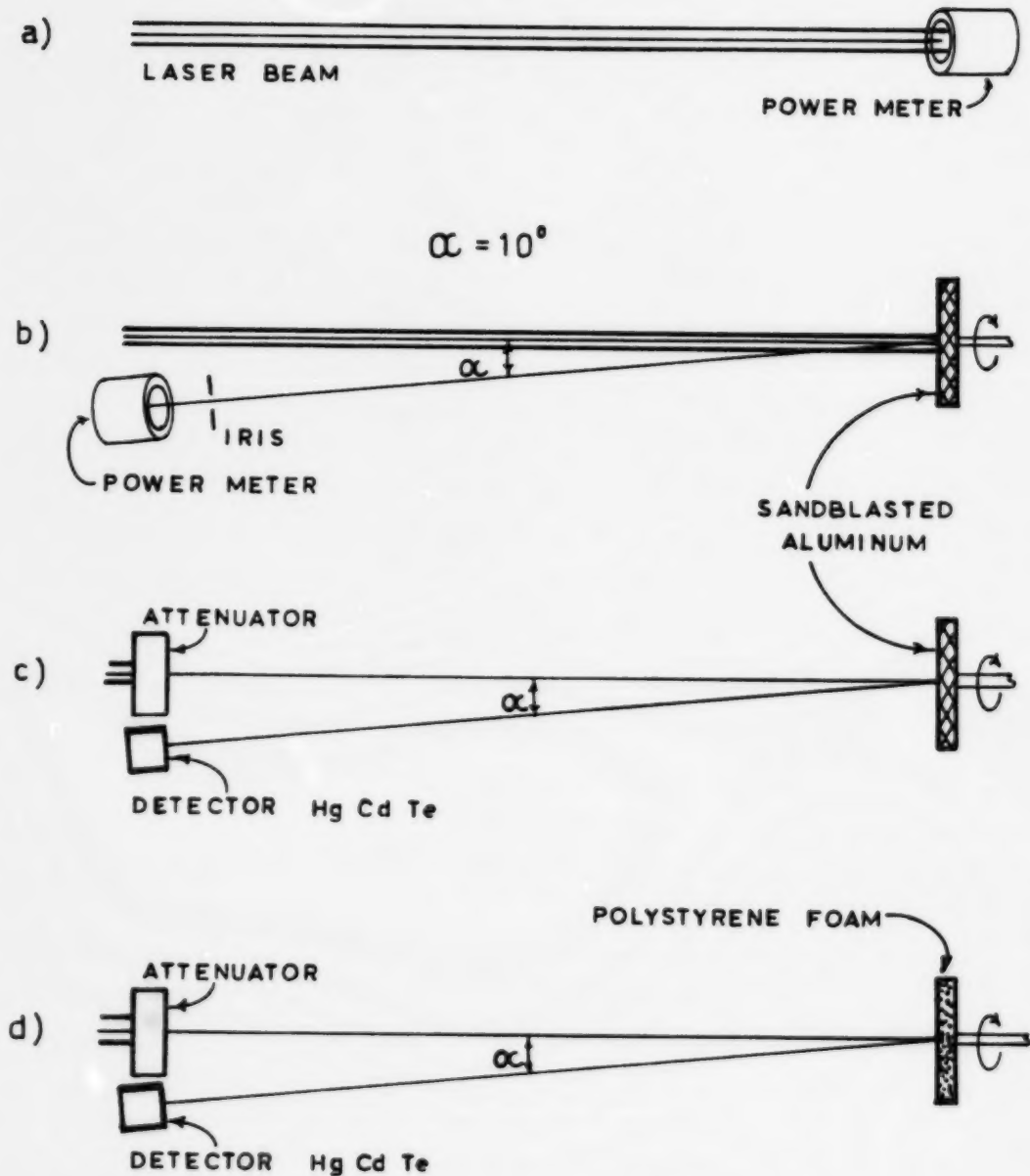


FIGURE 5 - Apparatus and procedure used to calibrate the styrofoam reference target without damaging its surface

5.0 BEAM DEPOLARIZATION

When a polarized laser beam is reflected from a diffusing surface, a certain portion of the reflected power is usually depolarized. The reflected power can be divided into parallel and cross-polarization components. To measure the parallel polarization component, we placed an optical polarizer in front of the detector with its axis oriented parallel to the polarization of the incident beam (i.e. maximum transmission of incident beam). For the cross-polarization component, the polarizer's axis was orthogonal to the polarization of the incident beam.

Data on beam depolarization becomes significant when working with laser radars which detect only one component of polarization (e.g. heterodyne detection systems; some monostatic configurations in which the difference in polarization is utilized in the beam duplexer).

5.1 Measurement of Beam Depolarization

The apparatus used to measure the parallel and cross-polarization components of the reflected beam is shown in Fig. 6. Each target was in turn mounted on the target holder previously described in Chapter 2.0. In the measurement apparatus, an iris was used to limit the reflected beam to the central area of the polarizer and a small lens increased the power level on the detector. All components were carefully aligned by using adjustable mounts. The axis of the polarizer was determined by placing a metalized polished spherical surface (i.e. a surface which does not depolarize the incident beam) centered in the beam at the target position. The axis of the polarizer was rotated to detect the maximum signal level. This position of maximum signal would be used to measure the parallel polarization component. By rotating the beam polarizer through $\pm 90^\circ$ it was determined that the polarizer had an extinction ratio of 600 to 1.

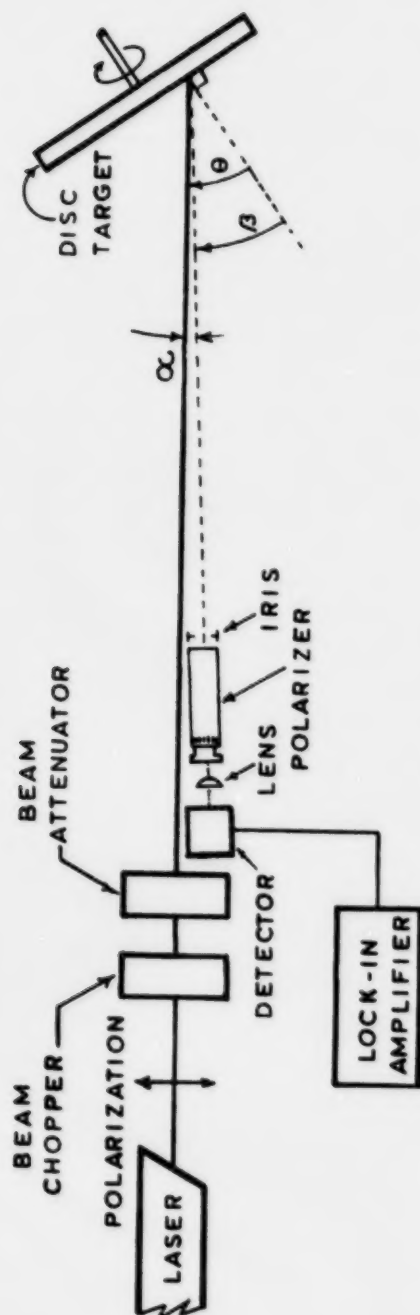


FIGURE 6 - Apparatus used to measure the parallel and cross-polarization components of the reflected beam

TABLE I
Parallel polarization component

<u>Material</u>	<u>Target illumination angle θ</u>							
	0°	1°	3°	5°	20°	30°	40°	45°
Blue polystyrene foam	.706			.705	.709	.712	.721	.740
Exposed blue polystyrene foam	.694				.700	.707		
USA blue polystyrene foam	.777				.779	.787		
Canvas	.787		.785	.782	.775	.765	.760	
Jute	.844		.838	.840	.823	.807	.809	.810
Sandblasted aluminum	.857					.815		
Silicon carbide abrasive-80 grit	.934					.933		
Silicon carbide abrasive-150 grit	.983					.959		
Silicon carbide abrasive-400 grit	.989					.925		
Sulfur	.995	.732	.678	.677		.673		

TABLE II
Cross-polarization component

<u>Material</u>	<u>Target illumination angle θ</u>							
	0°	1°	3°	5°	20°	30°	40°	45°
Blue polystyrene foam	.294			.295	.291	.288	.279	.260
Exposed blue polystyrene foam	.306				.300	.293		
USA blue polystyrene foam	.223				.221	.213		
Canvas	.213		.215	.218	.225	.235	.240	
Jute	.157		.162	.160	.177	.193	.191	.190
Sandblasted aluminum	.143					.185		
Silicon carbide abrasive-80 grit	.0664					.0672		
Silicon carbide abrasive-150 grit	.0166					.041		
Silicon carbide abrasive-400 grit	.0105					.0733		
Sulfur	.0049	.268	.322	.323		.327		

The targets were in turn mounted on the spinning mount (to provide speckle averaging) and the reflected signal power was measured for both its parallel and cross-polarization components. The measured powers expressed as a portion of the total power (i.e. the power in both polarizations) are tabulated in Tables I and II for the parallel and cross-polarization components respectively. In these tables the values have been tabulated for different values of θ , the target illumination angle, but as α was fixed at 0.8° in all cases, θ and β were close to being equal.

6.0 DISCUSSION OF RESULTS

After examining the measurement results from the different target materials, it was decided that the reflected power could best be described in terms of diffuse, specular and retroreflection components. The diffuse component is the power which has been scattered upon reflection, the specular component has been reflected in a mirror-like manner, and the retroreflection component has been directed back along the axis of the incident beam independent of target illumination angle θ . The individual materials will now be discussed.

The three samples of polystyrene foam exhibited characteristics of interest for a reference target. If the target was used with a monostatic laser radar (i.e. $\alpha = 0$) the reflectivity of the target would vary in the smooth and predictable manner depicted in Figs. 2a, 2b and 2c. As Figs. 2a, 2b and 2c do not show any marked increase in signal level as β approaches -1.5° , the reflected power does not appear to have a specular component (compare Fig. 2a to Fig. 2h which does show specular component). As with most other diffusing reflectors, a retroreflection component was however detected (Figs. 4a, 4b and 4c at $\beta = 0^\circ$ for $\theta = 0^\circ$, and at $\beta = 30^\circ$ for $\theta = 30^\circ$). This retroreflected signal explains why the measured reflectivity curves in Figs. 2a, 2b and 2c are broader than those indicated by the dashed line for a Lambertian target. For the curves plotted in Figs. 4a, 4b and 4c with

$\theta = 0^\circ$, the difference at $\beta = 0$ between the measured reflectivity and the dashed line (Lambertian target) is a measure of the error in ρ which would be introduced if the total reflectance of the styrofoam had been measured with an integrating sphere and its reflectivity characteristics assumed to be Lambertian. It is also to be noted that polystyrene foam materials from different sources have widely varying values of ρ (compare Figs. 2a and 2c). In general, polystyrene foam of a given type does constitute an acceptable reference target material for laser radar measurements. It is however, rather awkward to transport and to handle in large panel sizes.

The three SiC abrasive papers exhibit an increase in specular reflectivity as they progress from coarse to fine grit papers (note increase in ρ as $\beta \rightarrow 1.5^\circ$ in Figs. 2d, 2e, 2f. In Figs. 4d, 4e and 4f, the absence of a peak in detected power at $\beta = 0^\circ$ for the curves of $\theta = 0^\circ$, and at $\beta = 30^\circ$ for the curves of $\theta = 30^\circ$ indicates that the reflected power does not have a significant retroreflection component. However, on these curves an irregular pattern of reflectivity was recorded especially as $\beta \rightarrow 0$. The specular reflectivity, the absence of retroreflection and the irregular reflectivity values may be attributed to the fact that the SiC material visually resembles a many faceted mirror when examined under a microscope and behaves like crushed mirror particles (Ref. 2) which have their orientation flattened to produce a general tendency towards the specular condition. Coarse (i.e. 80 grit) SiC abrasive paper appears to be an acceptable material for reference targets if one is willing to accept the variations in ρ which were measured at the peak of the curve ($\theta = 0^\circ$) in Fig. 4d. The finer SiC abrasive papers became more critical to angular alignment because of the specular nature of their reflectivity. A possible drawback for SiC abrasive papers as fieldable reference targets is that the material is not readily available in large sheets (e.g. 1 m $\times$ 1 m).

All three samples of sandblasted aluminum, and especially the one prepared with a fine grain size, showed a significant specular reflectivity component. The coarsely sandblasted plates also exhibited retroreflection components (see Fig. 4i at $\beta = 30^\circ$ for curve of $\theta = 30^\circ$). Because of the specular nature of its reflectivity characteristics and the possible surface variations which can occur during preparation, sandblasted aluminum was not considered as one of the better materials for reference targets for calibrating 10.6- μ m laser radars in the field. It is however very weather resistant.

When the woven materials (canvas and jute) were turned to change target aspect angle, they showed greater variations in target reflectivity near $\beta = 0^\circ$ than a Lambertian reflectivity target would produce (Figs. 2j and 2k). The angular alignment of the canvas target in the field, however, would normally pose no problem. As seen in Figs. 4j and 4k, retroreflection produces a significant increase in reflectivity for monostatic systems (i.e. when $\alpha = 0$). Although both of these materials have acceptable reflectivity characteristics and could be used as reference targets, canvas was our preferred material because of its durability and ease of handling. In the field trial situation, a large canvas tarpaulin can be folded for transportation and then supported against a flat surface when performing calibrated measurements.

Although sulfur targets have been used as laboratory reference targets (Refs. 4 and 6), our experiments have shown that this material is not particularly suited for this purpose. Certain angular conditions produced high reflectivity values which are attributed to both specular reflection and retroreflection (see Figs. 2l and 4l). It is thought the magnitude of the specular reflection depends upon the target preparation method and the hazard of aligning the surfaces of the crystals. Furthermore, sulfur is poorly suited for use in an outdoor environment. For monostatic laser radar work, the retroreflection component for sulfur contributes considerably to the detected signal (see Figs. 4l for $\theta = \beta = 30^\circ$) and as a result the reflectivity varies

significantly from that of a Lambertian reflector. Our measurements indicate that, contrary to the practice reported in the literature (Ref. 6), ρ for laser radar targets should not be determined from measurements of total reflectivity carried out on this material in an integrating sphere.

7.0 CONCLUSIONS

In our search for a laser radar reference target for the 10.6- μ m wavelength, we have measured the reflectivity characteristics of twelve sample materials. These materials were found to have components of reflectivity which could be labelled as diffuse, specular and retroreflective.

The measurements carried out have shown that targets cannot be assumed to have Lambertian reflectivity characteristics even if the signal detected by the laser radar varies as the cosine of the target aspect angle (i.e. for an extended target). We have found that a retroreflection component of reflectivity is often present and that the total reflectivity, as seen by a laser radar in a monostatic configuration, is greater than that produced by a Lambertian target. For example with the blue polystyrene foam (styrofoam) at normal beam incidence, if the target reflectivity ρ had been calculated from a total reflectance measurement and by assuming a Lambertian reflector, the calculated reflectivity would have been 0.72 of the true reflectivity seen by a monostatic laser radar.

Because of the uniform nature of its prepared surface, the polystyrene foam target has proven to be an easy-to-use standard in the laboratory for determining ρ for other target materials. Caution was exercised not to use incident power levels which would damage its surface. For field measurements, canvas tarpaulins were preferred because they are less fragile and can be easily folded for transportation.

8.0 ACKNOWLEDGEMENTS

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9.0 REFERENCES

1. Meacock, H.F., Garforth, F.A. and Shrubsall, R.G., "The Luminance Factor of Smoked Magnesium Oxide at Small Angles of View", J. Sci. Instrum., Vol. 39, pp. 384-386, 1962.
2. Clarke, F.J.J., Garforth, F.A. and Parry, D.J., "Goniophotometric and Polarization Properties of White Reflection Standard Materials", Lighting Research and Technology, Vol. 15, No. 3, p. 147, 1983.
3. Henshall, H., St-Pierre, P. and Courtenay, T.H., "Measurements of the Reflectance of Materials at 10.6 Microns Using a TEA-CO₂ Ladar", DREV R-4051/76, June 1976, UNCLASSIFIED
4. Post, M.J., Richter, R.A., Keeler, R.J., Hardesty, R.M., Lawrence, T.R. and Hall, F.F., "Calibration of Coherent Lidar Targets", Appl. Opt., Vol. 19, p. 2828, 1980.
5. Dainty, J.C., Goodman, J.W., Parry, G., McKechnie, T.S., Françon, M. and Ennos, A.E., "Laser Speckle and Related Phenomena", Topics in Applied Physics, Vol. 9, Springer-Verlag, Berlin, Heidelberg, New York, 1975.
6. Kavaya, M.J., Menzies, R.T., Haner, D.A., Oppenheim, U.P. and Flamant, P.H., "Target Reflectance Measurements for Calibration of Lidar Atmospheric Backscatter Data", Appl. Opt., Vol. 22, p. 2619, 1983.

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APPENDIX A

Reflectivity versus Polar Angles

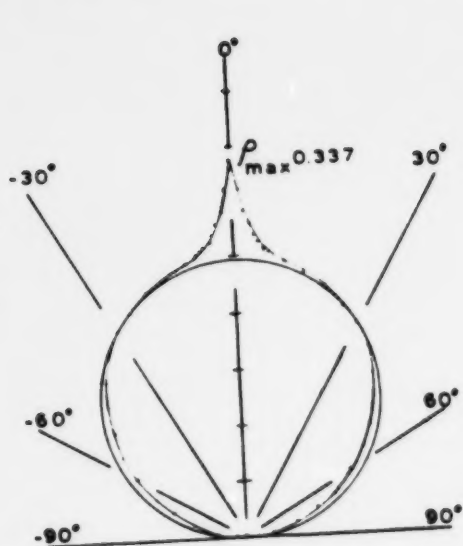


FIGURE A1(a) - Blue polystyrene foam
(Styrofoam SM, Dow
Chemicals of Canada)

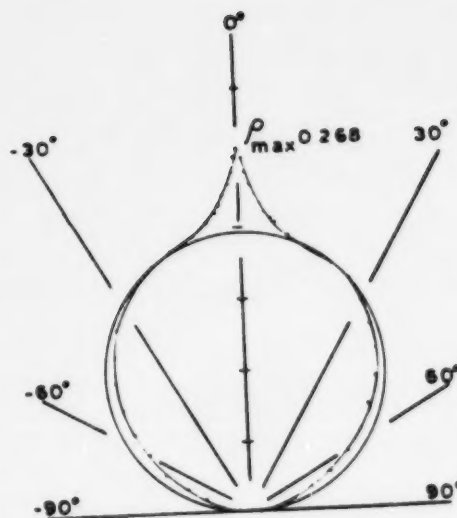


FIGURE A1(b) - Exposed blue polystyrene
foam (same as Fig. A1(a))
except surface deterior-
ated by weathering)

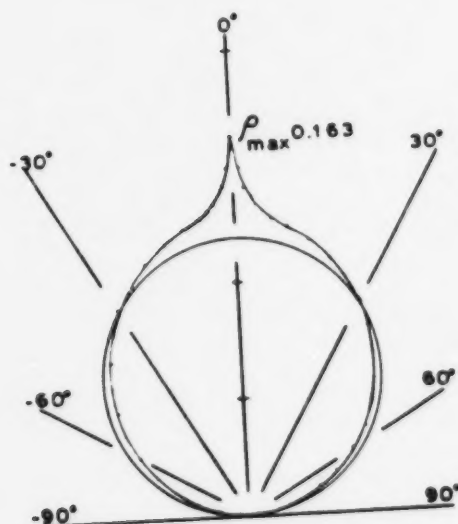


FIGURE A1(c) - USA blue polystyrene foam
(sample obtained from
Canada - US exchange)

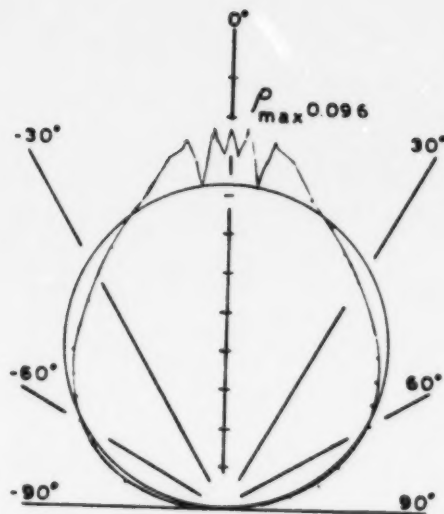


FIGURE A1(d) - Silicon carbide abrasive
(Norton Closekote Durite
SiC 80C waterproof paper)

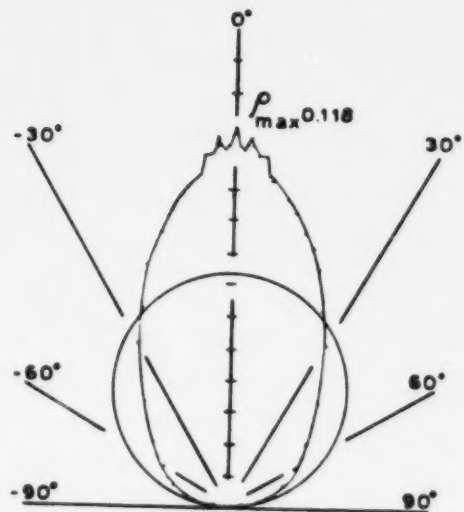


FIGURE A1(e) - Silicon carbide abrasive
(Norton Closekote Durite
SiC 150C waterproof paper)

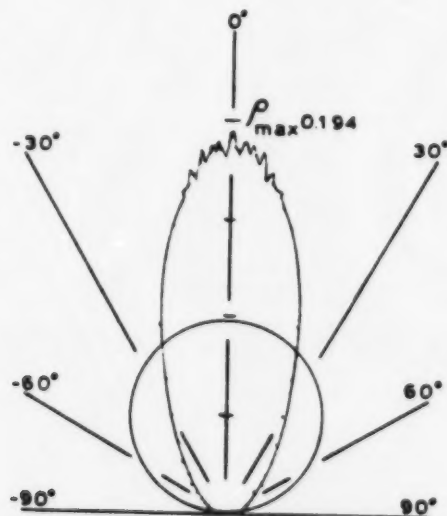


FIGURE A1(f) - Silicon carbide abrasive
(Norton Closekote Durite
SiC 400A waterproof paper)

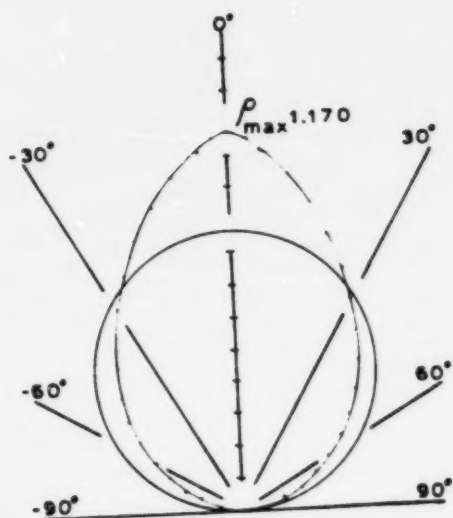


FIGURE A1(g) - Gold coated, coarsely sandblasted aluminum

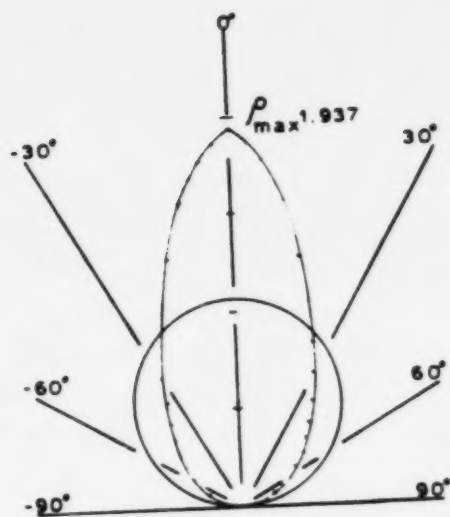


FIGURE A1(h) - Gold coated, finely sandblasted aluminum

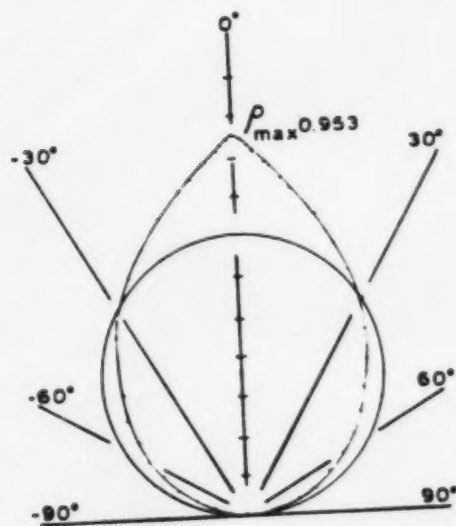


FIGURE A1(i) - Coarsely sandblasted aluminum

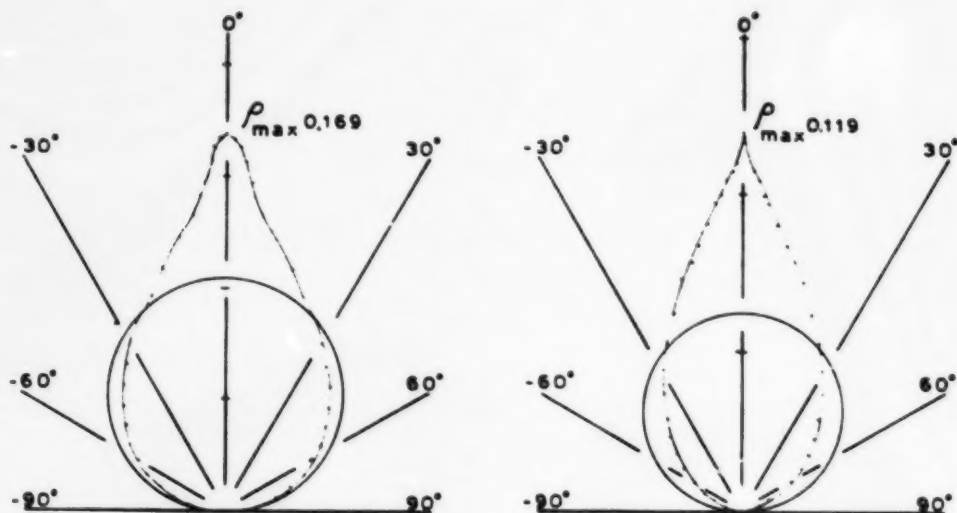


FIGURE A1(j) - Canvas marine and tent duck, FIGURE A1(k) - Jute cloth (10 oz. color mineral linen (Otis Permasol 10 oz. treated) natural jute, Scythes Inc., Toronto)

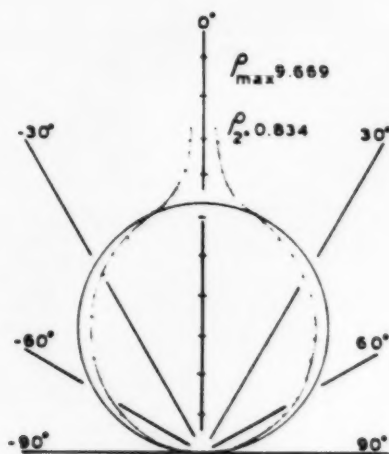


FIGURE A1(l) - Sublimed sulfur (Sublimed sulfur S591, Fisher Scientific Co.)
The off-scale peak value for ρ at $\theta = 0^\circ$ is 9.66.

FIGURE A1 - Polar plot of reflectivity ρ versus detector viewing angle β for a target illumination angle of $\theta = 0^\circ$. The circle is the reflectivity which would be measured from a Lambertian surface with $\theta = 0^\circ$ and a total reflectance equivalent to that of the target.

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